VALVE FOR LIQUID PERCUSSION DRILL

FIG. 2

FIG. 3

FIG. 4

FIG. 5

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FIG. 6

10
20
56
54
58
78
78 B
42
59
59 B

FIG. 7

A
B
A'
B'
C
C'

FIG. 8

104
106
104'
106'

FIG. 9

101
102
103
110
58
78 B

FIG. 10

100
115
58
78

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ABSTRACT OF THE DISCLOSURE

This invention relates to a liquid actuated percussion tool for applying repeated blows to a drill bit in the drilling of wells. The tool is connected to the lower end of the drill string just above the bit. The tool includes a hammer slideably fitted within a housing and an axially hollow anvil fitted within the housing below the lower end of the hammer. Means are provided so that the hammer rotates with respect to the anvil. The hammer is actuated by valve action on a fluid stream flowing in the axial hollow portion. The valve means includes an inner annular valve seat in the upper portion of the anvil which contacts the lower surface of a valve element. In this invention, this valve element is slideably positioned about a valve stem and is held in position by differential pressure acting on opposite sides thereof. Thus the valve element does not have to be rigidly attached to the valve stem, which connection has heretofore been a source of breakdown.

This invention relates to fluid actuated tools for applying repeated percussive blows to a drill bit in the drilling of oil and gas wells and the like. In particular, the invention is related to the percussive motors for incorporation in drill strings, causing drill bits to vibrate or oscillate axially at the same that they are being rotated for the drilling of such wells. This invention relates especially to improvements in valve means in percussive motors such as described in U.S. Patent 3,527,790, and in our co-pending application S.N. 691,082, "Drilling Apparatus," filed Nov. 1, 1967.

BACKGROUND OF THE INVENTION

A number of designs of percussion motors for drilling boreholes in the earth have been suggested in the past. Prior to the development of our tool as generally described in the above patent, those which had a measure of success have been designed for use with a stream of high pressure gas, such as compressed air or natural gas. The percussion motor is mounted at the lower end of the drill string and in turn is connected to a suitable drilling bit. The stream of high pressure gas, circulating through the drill string, percussion motors and bit, causes the bit to oscillate percussively against the formation and thus produces a major part of the drilling effect. The drill string is constantly rotated, both to produce a further drilling effect and to minimize deviations in the direction of the hole. The compressed gas from the percussion motor normally flows out ports in the bit and up the annulus between the walls of the hole and the drill string, carrying formation cuttings and well fluids to the surface. Although the use of compressed gas has proved quite advantageous in the drilling of many wells, there are many situations encountered where compressed gas cannot be used as the drilling fluid. Many times it is necessary to use liquids (customarily a water or an oil base drilling fluid) to control flows of formation fluids into the well and to carry formation cuttings to the surface. It is well known that the hydraulic head imposed by the column of liquid in the borehole affects control against flow of formation fluids into the well bore. The previously used percussion motors which were designed primarily for compressed air or gas do not at all work well when the drilling fluid is liquid. Our U.S. Patent 3,527,790 describes percussion motors which are especially designed for operations when the circulating drilling fluid is a liquid. Even though drilling liquids returning to the surface usually pass through vibrating screens and are circulated through settling zones in the mud pit, it is substantially impossible to produce a stream of material to be recirculated through the drill string which contains no quantity of abrasive solids. Accordingly, there is a very difficult problem in the design of liquid actuated percussive drilling motors to maintain valve operations without excessive abrasion and resulting wear. Another problem resulting in the frequent failure of the valves of a liquid percussion tool is the impact with which the valve strikes the seat. It is an object of this invention to provide an improvement in the valve system of such percussive motor so that such wear is greatly reduced.

BRIEF DESCRIPTION OF THE INVENTION

Briefly, in a preferred embodiment this invention includes a loose ring-shaped valve head for use in the valving system of the liquid percussion drill tool. This percussion drilling tool includes a housing, an axially hollow hammer slideably disposed within and closely fitting the housing and movable between an upper position and a lower position. The hammer has a first ring-type seat disposed around the bore thereof. A hollow anvil is slideably positioned within and closely fitting the interior of said housing and is positioned adjacent the lower end of the hammer. Means are provided to cause the hammer to rotate with respect to the anvil. The hammer is reciprocated between an upper position and a lower position contacting said anvil by valve action means on a fluid stream flowing in the axially hollow portion thereof. The valve means includes a hollow valve stem having a piston mounted on the upper end. Valve guide means are supported by the housing within said hammer for guiding the valve stem and a valve piston. In this invention, a ring-shaped valve head is slideably mounted on the lower end of the valve stem. The valve head is not attached to the valve stem but rather is held in position on the stem by the differential pressure which exists across the valve head. The anvil contains an annular valve seat which is concentric with the main bore of the anvil. However, just below this seat is a bore of a rather short longitudinal dimension. This short bore is eccentric with respect to the annular valve seat. As will be discussed, this is most important in avoiding wear patterns which would make the valving inoperative.

Various objects and a better understanding of the invention can be had from the following description taken in conjunction with the drawings.

DRAWINGS

FIGURE 1A and FIGURE 1B illustrate, respectively, the lower portion and the upper portion of the tool partly in section, showing the ring-type valve head seated in the annular seat in the anvil;

FIGURES 2–6 are representations illustrating various phases during the operation of the percussion tool;

FIGURE 7 shows a cross-section of the anvil valve seat and associated bores thereof;

FIGURE 8 is circles illustrating the eccentricity of the anvil valve seat and a bore in the anvil immediately below the seat;

FIGURE 9 shows in section a fragmentary part of the valve and anvil seat;

FIGURE 10 is similar to FIGURE 9 but indicates a wear pattern;

FIGURE 11 shows in section a fragmentary portion of the valve and hammer seat;
FIGURE 12 is similar to FIGURE 11 but indicates a wear pattern; FIGURE 13 is a fragmentary section of the ring-shaped valve head, valve stem and anvil seat; FIGURE 14 illustrates grooves in the bottom of the hammer.

Detailed description

A percussion motor normally contains two basic moving parts, which are a piston-type hammer and one or more valves to divert the flowing fluid into proper channels to cause the hammer to reciprocate. Although this invention is primarily concerned with improved valving construction and arrangement, such improvement involves both of these basic moving parts as the two cooperate to produce the desired valving action. A brief explanation will be given of the entire motor and particularly of how the valve assembly cooperates with the other parts so that a full appreciation and understanding of the improved valving system can be had. In addition to the piston-type hammer and valve assembly, a percussion motor has a casing or housing to confine the actuating fluid and an anvil slideably mounted within the housing below the hammer; however, the anvil is arranged for only limited axial motion. The housing can transmit the customary downward force from the drill collars through the anvil to the bit.

The anvil is arranged so that its upper face receives impacts from a lower face of the hammer upon its reciprocal motion. The lower end of the anvil is connected to the drilling bit. The anvil additionally is provided with splines and projections mating with similar splines and projections in the inside lower portion of the housing so that torque applied to the housing from the drill string will rotate the drill bit while percussive drilling is proceeding.

In operation, the percussion motor is mounted at the bottom of a string of drill pipe. The drill string is rotated from the surface and a high-pressure fluid is directed downward through it. The fluid does work in passing through the percussion motor and is exhausted from an exhaust passageway in the drill bit. The drilling fluid experiences a considerable drop in pressure as it passes through the drilling tool and drill bit, the pressure of the fluid in the annulus between the tool and borehole normally being from 100 to 600 or 800 pounds, or more, less than the pressure of the fluid in the drill string. This difference in pressure is used to advantage in reciprocating the hammer.

The central valve assembly oscillates between an upper and a lower position which causes hydraulic force to be applied alternately to the top and bottom of the slideable hammer, causing it to oscillate axially, i.e., vertically. After each upward stroke of the hammer, it is impelled downward to impact on the anvil, thus in turn causing the anvil to apply a series of percussive blows to the drill bit in contact with the earth formation. As will be seen, the present improved valve means is arranged to include wear, especially ending of the valve members. Our invention is directed primarily toward such improved valve assembly.

Attention is now directed to the drawings and especially to FIGURES 1A and 1B. Shown thereon is a tubular housing 10 which is attached by sub 50 to the lower end of a conventional drill string (not shown). Tubular housing 10 includes an upper portion 12 of a smaller inside diameter than that of the lower portion 14. There is a radial port 18 through the wall of housing 10 below but near the junction 16 of the upper and lower portions.

A hollow, stepped, cylindrical hammer 20 is mounted for axial movement within housing 10. The upper outer diameter of hammer 20 is matched to closely fit in the upper portion 12 of housing 10. Similarly, the lower outer diameter of hammer 20 closely fits the adjacent lower portion 14 of housing 10. Seals 22 and 24 are preferably provided between the hammer and the housing in the upper and lower portions thereof. The tool includes a hollow bore 26 in its upper end which is in direct and free communication with the drill string when in operation. The tool is arranged so that there is essentially no leakage of fluid from hollow bore 26 to sub 50.

As shown in FIGURE 14, the bottom surface 38 of hammer 20 has a plurality of grooves 39 which conduct fluid from the outer edge of surface 38 towards the center of the tool as the hammer approaches impact with anvil 28. Grooves 39 are inclined at an angle from radial lines emanating from the center axis of the hammer, so that the liquid escaping from the hammer is directed towards the bit, rotating moment on the hammer. The motion of the hammer rotating about its axis gives relative motion between the hammer and the case, the seals, the valve, and the valve seats, greatly extending their life by eliminating channeling type fluid erosion.

Slideshapedly mounted for limited axial movement in the lower end of housing 10 is anvil 28. At the lower end, anvil 28 is provided with means for transmitting torque from housing 10 to a drill bit (not shown) which is attachable to the lower end thereof in a conventional manner such as by threads 30. Various modifications of torque transmission arrangements are shown in FIGURE 1A in which the lowermost part of the housing contains a plurality of vertical ridges 32 between each two of which are splines or grooves. These ridges 32 engage equivalent splines or grooves cut into, or otherwise provided on, the outer periphery of the lower portion of anvil 28. The lower portion 28A of anvil 28 is enlarged to approximately the same diameter as that of housing 10. Upper surface 102 of anvil portion 28A is designed to receive lower end 100 of housing 10 so that a portion of the weight of the drill string above may be applied to the bit, thus improving its effectiveness in drilling. The splines in both the anvil 28 and the housing 10 are longer than the corresponding or mating ridges so that until the drill bit touches bottom, there is a vertical distance that anvil 28 can move between the position shown in FIGURE 1A and a lower position in which adjacent splines and ridges are in top contact. Suitable means, not specifically described, are provided to limit this vertical downward movement, typically from about one to about three inches. Full extension renders the hammer inactive when liquid is being circulated through the tool.

Anvil 28 is provided with a central bore 34. The top surface 36 of anvil 28 mates with the bottom surface 38 of hammer 20. Surface 36 is provided with a plurality of grooves 40. Also provided within anvil 28 are a plurality of conduits 42 which extend from surface 36 to within bore 34. Grooves 40 are intercepted by or otherwise are in fluid communication with conduits 42. These various grooves and conduits, singly or in combination, permit the liquid between hammer and anvil to be quickly evacuated so as not to cushion impact between the two.

A center valve guide or guide tube 46 is supported in housing 10 which is connected by threads to sub 50. A ball joint 48 is secured to the upper end of guide tube 46 and mates with ball joint sockets 47 which are mounted in recess 51 of sub 50. Spacer 49 and spacer spring 51 hold the ball joint and socket in position. Near the lower end of the guide tube, web type guide means 53 supported within the hammer is provided to accurately center the tube within the hollow portion of the hammer yet readily permit fluid to flow in the annular space between the guide tube 46 and the interior of the hammer 20. Other connecting means can be used.

As shown in the drawing, sub 50 also provides the means for connecting to the drilling string. Center valve tube 46 is provided for use in controlling movement of the valve assembly. Tube 46 is preferably a thin-walled pipe of uniform diameter, concentrically mounted in housing 10. The upper end of valve tube 46 is in direct fluid
communication with fluid channel 26. The upper end of valve guide tube 46 is provided with a plurality of ports 52 which are of sufficient size and number so that there is very little pressure drop between the pressure of the fluid in the fluid channel 26 and fluid channel 55 which is in the annular space between the exterior of valve tube 46 and the interior of hammer 20.

A main valve assembly is provided for the lower end of valve tube 46 and includes a valve stem 54, a valve piston 56 and a loose ring-shaped valve head 58 having an upper valve surface 58A and a lower valve surface 58B. Valve piston 56 is sealingly fitted within the lower end of valve tube guide 46. Ring valve head 58 is slideably mounted on the lower end of valve stem 54 and is prevented from falling off by shoulder 59 which is an enlarged portion of the lower end of valve stem 54. When assembling the valve assembly, valve head 58 is lowered down over the upper end of valve stem 54, followed by hammer seat 58 and end member 60. Valve piston 56 is then attached over the upper end of the stem. This can be accomplished, for example, by silver brazing the piston to the valve stem. The melting temperature of the silver braze material and the heat treating temperature of the piston material are selected so that both fastening and the hardening of the piston can be done in one operation.

A lower interior configuration which complements and matches with the outer portion 59A of enlarged shoulder 59 of the valve stem 54. During normal operation valve head 58, as explained more fully later, is held in position by the differential pressure which exists across this valve head. The advantages of such a system over rigidly attaching the valve head to the valve stem will be discussed hereinafter.

Valve stem 54 slindingly extends in a sealing relationship through end member 60 of valve tube 46. Just above end member 60 are a plurality of ports 62 in the wall of valve tube 46. Valve stem 54 is of a sufficient length that when the most part of the fluid is in the annulus as shown in FIGURE 1 of the drawing, there is a cavity 64 within valve tube 46 below valve piston 56. When piston 56 is above ports 62, cavity 64 has substantially the same pressure as the pressure P2 in annulus 55 between valve tube 46 and hammer 20. This pressure acts against an area AY which is the horizontal component of the area of the lower side of valve piston 56 which is in communication with cavity 46. Mounted within valve tube guide 46 above valve piston 56 is a fluid restriction means which is shown in the drawing as a nozzle or choke 66. This nozzle functions so that the pressure P1 within the interior 45 of valve guide tube 46, between piston 56 and nozzle 66, is always substantially less than pressure P2 in the annulus between the valve tube 46 and the hammer with an exception which will be shown later when ports 62 are in communication with interior 45. In other words, this arrangement provides a reduced pressure to act downwardly against the effective horizontal component AY of the valve piston 56. Nozzle 66 should be a sufficient distance above piston 56 so that no appreciable jetting action is imparted to the valve piston.

Attention will now be directed toward means for stopping the upward movement of valve assembly (54, 56, 58). This can, in effect, be considered a dashpot stop. The upper end of valve piston 56 includes an interior cavity 56C. The interior of valve guide tube 46 above piston 56 has a downwardly facing cavity 37. This cavity 37 is annular in shape and the size of cavity 37 is such as to slideably receive the upper end of valve head 56 which forms cavity 56C. The entrainment of fluids in cavity 37 of the upper end of valve head 56 reaches the lower surface 46A of the valve tube guide with the controlled fluid leak through the annulus between surfaces 46A and piston 56 causes a very effective dashpot type stopping of the upward movement of the valve assembly.

Both the upper 58A and lower 58B surfaces of valve head 58 function as a valve. Attention will now be directed toward a consideration of the seat assembly for the lower side of valve head 58 of the reciprocating main valve stem. A cylindrical anvil valve seat 76 which is in effect an enlargement of anvil bore 34 is provided in the upper end of anvil 28. The upward facing surface 78A of valve seat 76 is shaped to conform to the lower surface 58A of valve head 56. A second surface 78B, in the starting process, mates with the lower seat 59B of enlargement 59 of the valve stem 54 to stop the downward movement of the valve stem. To provide for proper differential areas, the largest (or seating) diameter of valve to head 58 is greater than the diameter of piston 56. Seat 78 can be mounted directly on recess 76 without use of a shock absorbing means inasmuch as the valve head 58 is hydraulically held in place. Specific configuration of the improved valve head and seats will be discussed in detail hereinafter, especially in conjunction with FIGURES 2-12.

Valve head 58, when closed against anvil seat 78A, prevents flow of fluid from annulus 55 and its extension annulus 87 to bore 34 within anvil 28. Annulus 55 is that space between the outer wall of valve guide 46 and the inner wall of hammer 20. As can be seen in the drawing, drilling fluid flows freely from the drill pipe down through ports 52 and into annulus 55.

Valve head 58 includes a carefully machined upper surface 58A. We shall now consider how this cooperates with the annular valve sleeve in the hammer. Near the bottom of stepped hammer 20, the bore of the hammer is decreased and an annular valve sleeve member 88 is provided, forming a hammer valve pocket. An annular valve seat 90 is provided in annular member 88 for the upper surface 58A of valve head 58. The bore 91 of valve member 88 is eccentric to the bore of stepped hammer 20.

Attention will not be directed toward the secondary or annular valve. This includes an annular ring valve 82 mounted on the interior of the lower end of hammer 20 above annular member 88. Valve 82 preferably is provided with hard facing 84. The lower slightly tapered portion 86 of lower member 60 of valve guide 46 is preferably a hard metal, such as sprayed-on tungsten carbide, and is carefully machined as is the interior of the hard facing 84 of the ring valve 82 so that as hammer 20 moves upwardly, ring valve 82 cooperates with the lower portion 86 to stop substantially all of the flow of fluid downwardly from annulus 55. There will still be flow from annulus 55 to cavity 64 (beneath piston 56 within valve guide 46) while the valve assembly 54, 56, 58 is moving upward.

In order to start the tool, the diameter on the shoulder 59 of the stem identified by point 117 must be larger than that demonstrated by point 119 of the anvil seat.

Having described the general configuration of the drilling tool, attention will now be directed toward its operation and particularly toward the inner relationship of different parts of the valve which have been found to be most important. The drawings show the drilling tool in what appears to be a vertical position. However, the tool can operate in any position—horizontal, vertical or upside down—since the valve action does not rely on gravity for effect. An operating cycle can begin with the parts in the relative positions illustrated in FIGURES 1A and 1B. There it can be seen that the primary valve, that is, valve head 58, is seated on the anvil valve seat 78. At this point in the cycle, hammer 20 is resting on anvil 28; however, in FIGURE 1A they are shown slightly separated for ease of identifying parts. The selection of the predominant forces on the valve and hammer when fluid pressure is applied through the drill string will now be made for each of the positions indicated in FIGURES 2-6 and FIGURES 1A and 1B. FIGURES 2-6 are drawn to illustrate primarily relative positions of the various parts for different phases of an operational cycle rather
than relative size. The hammer will start up from the position shown in FIGURE 1A because the net force on the hammer is up. This is shown by a consideration of the dominating hydraulic forces. The downward force on hammer 20 is

\[ P_2A_2 - P_3A_3 \]

where \( A_3 \) is the upper horizontal component of the area of the stepped hammer in contact with the fluid having pressure \( P_3 \), which is the pressure of the fluid in the well annulus exterior of the tool; \( A_2 \) is the horizontal component of the upper area of the stepped hammer in communication with the main stream of drilling fluid in annulus 53 at a pressure \( P_2 \). The upward force on hammer 20 is

\[ P_3A_3 \]

where \( A_3 \) is the horizontal component of the area of the lower surface of the hammer. As \( A_3 \) equals \( A_2 \), it is readily apparent that there is an upward force on hammer 20 due to the differential pressure.

The force on the valve assembly while the hammer is rising (and before ring valve 82 seats with or closes over seat 86 on exterior of valve guide member 46) will now be given. The force down is

\[ P_1(A_{VH} - A_{VB}) + P_4(A_{VP} - A_{VB}) \]

and the force up is

\[ P_3(A_{VP} - A_{VB}) + P_4(A_{VH} - A_{VB}) \]

where:

\( A_{VH} \) is cross-sectional area of valve head 58;
\( A_{VB} \) is cross-sectional area of valve stem; and
\( A_{VP} \) is cross-sectional area of valve piston 56.

\( P_1 \) is the larger pressure within cavity 64 and annulus 55.

\( P_4 \) is the reduced pressure of the fluid within bore 34, and as there is little flow at this moment between bore 34 and the exterior of the tool, except for the amount passing through choke 66, for this explanation it can be considered that \( P_4 \) is also the approximate pressure \( P_2 \) of the fluid in the well annulus exterior of the tool and also the approximate pressure \( P_1 \) within bore 45.

The net force at this time on the valve assembly is down and is

\[ (P_3 - P_1)(A_{VH}) - (P_4 - P_1)(A_{VP}) \]

as \( A_{VH} \) is greater than \( A_{VP} \) by construction.

Valve head 58 stays closed, i.e., seated in the anvil, until hammer 20 rises to a position shown in FIGURE 2 and the secondary valve closes, i.e., ring valve 82 slides over the lower portion 86 of valve guide 46. When this occurs, the cavity 87 below member 86 and exterior of stem 54 is shut off from the main stream of drilling fluid. As soon as annular member 84 is adjacent the lower end 86 of tube 46 it reduces the flow of fluid into cavity 87. This reduction in fluid flow is accompanied by a substantial decrease in pressure beneath hammer 20 since also the volume of the chamber 89 between the hammer 20 and the anvil 85 is expanding. When pressure in chamber 89 decreases sufficiently, the valve assembly will be forced up. The net force on the valve assembly is then

\[ (P_3 - P_1)(A_{VP}) + (P_4 - P_1)(A_{VH}) \]

where a positive designation represents upward force and negative sign represents a downward force.

\( P_3 \) is approaching \( P_2 \) because the volume of the cavity 87 and chamber 89 between the ring valve, i.e., upper annular valve 84, and the anvil face is expanding faster than fluid can "leak" past the ring valve. Therefore the net upward force on the valve is

\[ (P_3 - P_2)(A_{VH}) + (P_4 - P_2)(A_{VP}) \]

As this value is positive and \( P_3 \) is much greater than \( P_2 \) and \( A_{VH} \) is only slightly larger than \( A_{VP} \), the valve assembly is literally thrown upwardly. FIGURE 3 is similar to FIGURE 2 but shows the valve 58 at about one-half way up between the anvil and hammer seat. The valve continues upwardly until it encounters stopping means as illustrated in FIGURE 4. Cavity 47 is positioned with relation to piston 56 so that the valve assembly is stopped before valve head 58A contacts annular seat 90. If the valve were stopped by annular seat 90, then as the hammer and valve assembly move upward, cavity 87 would be decreasing in volume and the fluid captured therein would be increasing rapidly in pressure. This would cause the fluid to forcibly flow out of cavity 87 between annular seat 90 and valve head 58 preventing total closure of head 58 on seat 90, causing severe erosion. When the secondary valve, i.e., ring valve 82 closes, cavity 87 cannot shrink in volume after valve head 58 is stopped. Cavity 56C is so placed that valve head 58 is stopped at a position just below valve seat 90 when the hammer is in its upper position. The valve stop cavity 47 is also positioned so that the ring valve 82 is still closed (i.e., engaging valve member 86) when the annular seat 90 contacts valve head 58A on the hammer downwardstroke. Stopping of the hammer is effected by the closure of valve member 86 closing in ring valve 82. Downward motion of the hammer results in the expansion of cavity 87 which drops the pressure therein, allowing valve head 58 to close on seat 90 under no flow conditions. Valve surface 58A should seat with seat 90 before surface 84 of ring member 82 travels downwardly sufficient to clear point 17 on valve guide tube 46.

A brief consideration of the predominant force on the valve assembly (disregarding the force due to the weight of the assembly itself) will now be given when the various parts are in the position shown in FIGURE 4 in which piston 56 has engaged stop means such as a dashpot, ring valve 82 still closed and valve head 58 not seated anywhere. The net force on the valve is

\[ (P_2 - P_3)(A_{VP}) + (P_3 - P_2)(A_{VH}) \]

where the plus force is acting up and the negative down, and \( P_3 \) is the pressure in cavity 47. Since \( P_2 \) approaches \( P_3 \) then the net force is \((P_3 - P_2)(A_{VP})\), which is negative as \( P_3 \) is much greater than \( P_2 \) until the valve's momentum has been absorbed by displacing liquid from cavity 47 through the annulus between 46A and 56C.

When the flow of fluid is shut off or reduced beneath the surface \( A_3 \) of the hammer and valve 58 is stopped, the net downward force on the hammer rapidly exceeds the upward force and the hammer is forced downward. (On most of the down stroke the valve unit and hammer travel together.) When hammer 20 starts down, cavity 87 is increasing and essentially no fluid flows between seat 90 on the hammer and the upper valve surface 58A of the valve as it closes. In other words, after some downward movement, the hammer through valve seat 90 forces the valve down with it. The relative position of the parts are shown in FIGURE 5. The upward force on the valve is greater than the downward force because of the seal between the valve head 58A and the valve seat 90. The net force on the valve assembly due to fluid pressure is

\[ (P_2 - P_3)(A_{VP}) + P_3A_{VH} + P_3A_{WH} \]

where a positive designation is an upward force and a negative designation indicates that that force is downward, and \( A_{WH} \) is the area of valve head 58 in contact with fluid pressure \( P_3 \). By definition \( A_{WH} \) is greater than \( A_{VH} \) which is greater than \( A_{WH} \). Therefore the net force on the valve assembly is upward. The inside diameter of tube 46 is made greater than the minimum diameter of seat 90. When the hammer impacts the anvil, the hammer will move; however, the inertia of the valve will unseat it from the annular seat 90 and start the valve head 58A on seat 78A in the anvil as shown in FIGURE 1A. Now the valve no longer has a net upward force. The valve pocket 85, in closely fitting valve 58, serves a very useful purpose as it enables a pressure differential to be maintained across
valve element 58 so that it will continue to go down to seat 78.

Before the tool is started, the first thing to do is lower the entire tool to near the bottom of the hole. When in this condition, and when high pressure mud is pumped through the tool, the valve mechanisms take the position as indicated in FIGURE 6. There it is seen that lower ring-shaped valve head 58 is resting in seat 78 and valve surface 59B of enlarged portion 59 of the lower end of valve stem 54 is seated against stop 78B. It will further be observed that valve 58, in this position, is not resting on the upward facing shoulder of enlarged portion 59. The valve piston 56 is resting below ports 62 in valve more than 35. The curved surface in an upward position so that annular valve stem 82 engages member 86 of the central valve tube. The major portion of the mud flows down annulus 55, ports 62, above and around piston 56, down the hollow valve stem 54, through anvil passage 34, through the bit into the well-tool annulus. A small portion of the mud flow in annulus 55 passes between 82 and 86 into cavities 86 and 89, and thence into anvil conduit 42 leading to anvil bore 34. Starting the tool is accomplished by lowering it to the bottom of the well where the anvil shoulder 28A is moved upward to contact the lower end of case 10. Anvil seat stop 78B, pushing against stem enlargement 59 raises stem 54 and attached valve piston 56 past ports 62 of valve tube 46. The flow of mud is now restricted and forced to flow through the annular clearance between the ring valve stem and center tube 86, effecting a rapid rise in pressure in annulus 55 and thus through ports 62 to the underside of piston 56. The pressure in passage 87 is much less due to the leak off through conduits 42. The hydraulic downward force \( (P_y - P_f) A_{VP} \) on the valve head is less than the upward hydraulic force \( (P_f - P) A_{VP} \) on the valve position, so the valve shifts upward, reaching the position in FIGURE 4. Normal reciprocation of the hammer then continues.

In order to better understand the improved valve system of our percussion drill, attention is next directed especially to FIGURES 7, 8 and 9 which show in greater detail the configuration of the annular valve seat in the anvil and its relationship to the valve head. Shown in FIGURE 7 is a bore 100 and anvil 28. This bore 100 is just above seat stop 78B and below anvil seat 101. Anvil seat 101 curves into a vertical portion 102 which is tangent with the seat 101.

FIGURE 8 has circles 104 and 106 which, respectively, correspond to circles defined by bore 100 and by seat 101 and its vertical extension 102. Circles 104 and 106 are eccentric to each other; that is, 104 has a center at 104' and circle 106 has a center at 106'. The importance of this arrangement will become more apparent hereinafter from the following discussion.

Attention is now directed to FIGURE 9. As can be clearly seen, the valve 58 has a lower valve surface 58B which, in the section of FIGURE 9, is formed by a circle having a radius R and a center 110. Valve 58 also has an upright surface 103 which is concentric with vertical surface 102 of the anvil seat. The anvil seat is designed to receive a valve 58B. Seat portion 101 has a radius R in the same center 110 (that is, when the valve is seated) so that the anvil seat can readily receive the valve. The clearance between portion 103 of valve head 28 and portion 102 of the anvil seat is typically about .020 to .040 inch. The actual seating takes place at point F between the curved portion 58A of the valve and the curved portion 78B of the anvil seat. When the valve is new, a line tangent to the point of contact between the valve surface 58A and seat 78A preferably defines an angle of about 10° with the center line of the valve. Such an angle results in a lateral force equal to the vertical component of force times the cosine 10° by a factor of slightly more than 5. The curved surfaces are designed so that the natural abrasion which occurs maintains a shape whereby the seal is always on the large diameter of the anvil seat.

There is usually a large amount of solid particles in the drilling fluid and this causes abrasion of the valve and seat. It has been found in some type valves formerly used that this abrasion can cause a pocket such that when the valve head 58 is forced downwardly, fluid is trapped in the pocket which prevents the valve from seating properly. Another form of abrasion which can occur wears on both the valve seat and valve, then in some cases the valve might seal at the point where the diameter may be less than the diameter of the piston, then the valve would stall due to improper differential areas. In some cases, these problems force early replacement of the valves and seats. These problems are eliminated, or at least minimized, by the use of the present invention.

Again considering FIGURE 9 which shows the configuration of the valve head and anvil valve seat, it is essential that the seal occur at point F rather than point G. By the configuration we have, this always occurs, even after wear or abrasion. There is very little change in direction of the fluid at point F as the valve closes. As the direction of the fluid at point F is not changed, then as the valve closes, the erosion of the material at point F would be very small. Centrifugal force of fluid as it progresses from point F to point G, before actually closes, will cause some erosion on the lower surface of valve head 58B or along surface 101 near point C. As this erodes away more rapidly than the surface at point F, it is seen then that the seal will always be at point F instead of point G. The diameter of the circle formed by the contact at point F has to be greater than the diameter of the piston 56 for the tool to function properly. This system of controlled erosion assures that.

It has been found that if cylindrical bores 100 and 102 on FIGURE 10 are concentric, the wear pattern which develops will be similar to that shown by the solid line on the valve head at point G' wherein fluid trapped above point G' would prevent the valve head 58 from closing in anvil seat 78A. Also, the seal area would be confined to a circle defined by point G' which is less than the area of the piston 56, in which case the valve head would not remain on the anvil seat and the tool would not function. By the use of the present invention no fluid is trapped between the valve and the valve seat by any uneven wear of the valve head on the anvil seat. This condition is prevented by making circle 104 eccentric with respect to the circle 106 in FIGURE 8. That is, bore 100 is eccentric with respect to the tool, and the bore which defines upright portion 102 of the anvil valve seat is concentric with the bore of the anvil. As shown in FIGURE 7.

The wear pattern of valve head 58 resulting if surfaces 100 and 102 were eccentric is denoted by the dotted line 115 on FIGURE 10 adjacent to G'. It is also to be noted that the valve assembly (54, 56, 58, 59, etc.) rotates with respect to the tool. This feature is especially important in relation to eccentric bore 100 to prevent the type wear which would result in a dashpot being formed in effect. Such dashpot would prevent the valve from properly closing in the anvil seat such as shown by the solid line at point G' on FIGURE 10 and D in FIGURE 12.

The seat in the hammer is constructed similarly as that of the anvil seat except it is inverted as shown in FIGURE 11. In this case it is necessary that the seal area between the valve head 58 and the hammer valve seat be confined to a circle with a diameter indicated by point D. This seal area is less than that of the piston so that there can be a net upward force holding the valve head closed in its hammer. Erosion is less at point D because the fluid passing point D from the plenum above is traveling
tangent to the curve at point D whereas it is being forcibly curved as it moves downward from point D towards E. Also, the bore 91 of the hammer seat 88 is eccentric with its outer surface; therefore, the erosion on the upper surface 58A of valve head is distributed over a large area opposite point D on the hammer valve seat. This minimizes the wear as compared to that which occurs on the surfaces below point D. The eccentricity of the inner bore 91 of hammer seat 88 prevents a wear pattern such as shown in FIGURE 12, in which the valve head can wear to a cylindrical section such as is shown at point D. This condition will prevent the valve from closing properly in the hammer seat because of the dashpot action. The eccentricity assures clearance between the hammer valve seat and the valve head as is shown by the dotted line denoted as D'.

It was stated earlier that ring valve head 58 maintained its position on shoulder 59 of stem 54 due to differential pressure. By referring to FIGURE 13, an explanation can be given as to how this results. Valve head 58 is held in contact with the top surface 59 of the bottom enlargement of valve stem 54 by the differential pressure which is always present. There is a downward force on head 58 which is equal to the difference in pressure between cavities 87 and 34 acting on the difference in area between A\text{VH} and A\text{VS}. It is further secured by the difference in the ambient pressure in the well at depth and the vapor pressure of the drilling fluid acting on the difference in areas between A\text{max} (cross-sectional area of enlarged portion 59) and A\text{VS}. The lower limit of travel of the valve head 58 is the annul seat 78 or the surface 59 of the enlargement on the valve stem when the valve 54 is in positions other than that shown on FIGURE 13. It can be appreciated that the heavy mass of the valve stem 54 and the piston 46 is stopped hydraulically after valve head 58 comes to rest on annul seat 78. Thus, the stress due to impact is reduced many fold since only the relatively small mass of the head 58 is stopped mechanically. The mechanically stopped mass of the valve assembly is reduced by a factor of 6.

The improved design of the loose ring valve head will allow use of more wear resistant alloys for the valve head and seats, whose use before was limited by the difficulty in fastening (such as by brazing) such brittle alloys to the valve stem. Although there are disclosed above a limited number of illustrations of this invention, various modifications can be made thereto without departing from the spirit and scope of this invention.

We claim:

1. A percussion drilling tool including a housing, an axially hollow hammer slideably disposed within and closely fitting said housing and movable between an upper position and a lower position, said hammer having a ring-type seat disposed around the bore thereof but near the lower end, an axially hollow anvil having an annular seat at the upper end of said bore, said anvil slideably disposed within and closely fitting said housing and positioned adjacent one end of said hammer, said hammer being reciprocated between an upper position away from and a lower position contacting said anvil by valve action of valve means on a fluid stream flowing in the axially main hollow portion, said hammer including an annular valve head thereon, the improved valve means including:
   a. a hollow valve stem;
   b. valve guide means supported by said housing within said hammer for guiding said valve stem;
   c. a piston means mounted on the upper end of said valve stem and sealingly fitting the inner wall of said guide means;
   d. a ring valve head slideably mounted on the lower end of said valve stem, said ring valve head slideably mounted about and closely fitting said valve stem above said shoulder member, the upper side of said ring valve head forming an annular valve for sealing said hollow anvil seat and guiding said hammer and the lower side of said ring valve head forming an annular valve for seating on annul annular seat.

2. A percussion drilling tool as defined in claim 1 including an annular stop in said annvil and spaced below said ring valve head 58. Valve stem 54 may be an annular stop (78A) valve annular seat (78B) being of smaller diameter than said annul seat, said annul stop being arranged to receive a mating surface (59B) on the lower end of said shoulder member of said valve stem, a bore (100) between said annul seat and said annul stop, the axis of said bore being eccentric to the axis of said anvil, said annul seat being concentric to the main hollow portion of said anvil.

3. A percussion drilling tool as defined in claim 2 in which said annul seat of said hammer is contiguous to a short inner bore positioned just above said seat, said inner bore being of smaller diameter than said seat, said inner bore also being eccentric with respect to the bore of said hammer.

4. A drilling tool as defined in claim 3 wherein the lower face of said hammer contains non-radial grooves from the outer wall extending inwardly to the bore thereof so that as the hammer annular seat approaches the anvil, fluid imparts in the grooves imparts a rotary motion to the hammer.

5. A drilling tool as defined in claim 1 wherein the lower face of said hammer contains non-radial grooves from the outer wall extending to the bore thereof.

6. A percussion drilling tool for drilling a borehole and attachable to the lower end of a string of drill pipe, which comprises:
   a. a tubular housing adapted to be connected to said drill string and including a drilling fluid passage in the upper end thereof, said housing containing an upper portion of smaller inside diameter than that of a lower portion;
   b. a hollow annul mounted in the lower end of said tubular housing, the upper end of said anvil having a stepped cylinder recess and a first seat in the first portion of said stepped recess and a second seat in the stepped portion, said anvil including conduits extending from its upper surface to its hollow interior;
   c. an annular stepped hammer having an upper extension of lesser diameter than the lower portion thereof and positioned in said anvil housing, said cavity being in fluid communication with the exterior of said tubular housing, said hammer having an upper surface of its lower portion in fluid communication with said cavity, an upper surface of its extension in fluid communication with the drilling fluid passage of said housing and a lower surface, for striking said anvil;
   d. a cylindrical valve guide fixed to said housing and extending into the hollow portion of said hammer, there being an internal annular shoulder near the lower end of said valve guide forming a passage of reduced diameter, said ports in the wall of said guide immediately above said shoulder, the exterior of said valve guide being of a smaller diameter than the inside of said hammer, thus forming an annular space;
   e. means establishing fluid communication between said drilling fluid passage and the annular space between said valve guide and said hammer;
   f. a valve assembly having a longitudinal passage therethrough and an upper enlarged member positioned and sealingly fitting within said valve guide.
3,491,838

above the internal annular shoulder thereof, said valve assembly having a lower enlarged end having a downwardly facing shoulder acting as a valve when seated on the said second valve seat of said anvil; the valve assembly having a ring valve head slideably mounted on said valve stem above said enlarged end of said ring valve head adapted to seat on said first annular seat of said hollow anvil and thus forming a valve;

(g) a first annular valve seat element on and recessed within the lower end of said hammer for engagement with the upper side of said ring valve head of said valve assembly to form a valve means;

(h) an annular ring valve on the lower interior of said hammer above said first valve seat element and complementing the the exterior of the lower end of said valve guide to form a valve means;

(i) a choke in the upper end of said valve guide in fluid communication with said drilled fluid passage; and

(j) stop means in said valve guide and supported there-by for limiting the upper movement of said enlarged end member of said valve to a position spaced below said annular valve seat of said hammer when said hammer is in its upper position.

7. A drilling tool as defined in claim 6 in which the lower face of said hammer contains non-radial grooves from the outer wall extending to the bore thereof.

8. In a percussion drilling tool including a housing, an axially hollow hammer slideably disposed within and closely fitting said housing and movable between an upper position and a lower position, an axially hollow anvil slideably disposed within and closely fitting said housing and positioned adjacent the lower end of said hammer, said hammer being reciprocated between an upper position away from said housing and a lower position contacting, said anvil by valve action of valve means on a fluid stream flowing in the axially hollow portion, said hammer including an annular valve seat thereon, the improved valve means including:

a hollow valve stem;

valve guide means supported by said housing within said hammer for guiding said valve stem;

a piston means mounted on the upper end of said valve stem and sealingly fitting the inner wall of said valve guide means;

a valve means on the lower end of said valve stem; an annular seat within the upper end of said anvil for receiving said valve means, a vertical plane through said valve seat defining an arc of a circle, the upper end of said arc being tangent to a first bore and the other end of said arc being tangent to a second bore; said first bore and said main bore each having its center on the center axis of said anvil, said second bore being eccentric to said first bore, said second bore having a diameter not greater than about the smallest diameter of said annular seat.

9. An apparatus as defined in claim 8 in which said valve means supported on the lower end of said valve stem comprises:

a ring valve head slideably mounted on the lower end of said valve stem, a shoulder member secured to said valve stem for supporting said ring valve head, an upper side of said ring valve head forming an annular valve for seating on the said annular valve seat element, said valve seat element having a ring valve head forming an annular valve for seating on the said annvl valve seat.

10. A percussion drilling tool as defined in claim 8 including an interior annular shoulder member supported within the upper end of the bore of said anvil and spaced below said annular seat forming a stop for the said shoulder member carried at the lower end of said valve stem.

11. A drilling tool as defined in claim 8 in which the tangent with the ring valve head at the point of contact between the ring valve head and said anvil annular seat makes an angle of about 10° with the center line of said anvil when new.

12. In a percussion drilling tool including a housing, an axially hollow hammer slideably disposed within and closely fitting said housing and movable between an upper position and a lower position and having a ring-type seat disposed around the bore thereof near the lower end, an axially hollow anvil slideably disposed within and closely fitting said housing and positioned adjacent one end of said hammer, said hammer being reciprocated between an upper position away from and a lower position contacting said anvil by valve action of valve means on a fluid stream flowing in the axially main hollow portion, said hammer including an annular valve seat thereon, the improved hammer comprising:

a hollow hammer having a lower face characterized by non-radial grooves extending from near the outer edge of said face to the bore of said hammer so that when said hammer moves downwardly to strike said anvil that flow of fluid in said groove imparts a rotary motion to said hammer.

13. In a percussion drilling tool including a housing, an axially hollow hammer slideably disposed within and closely fitting said housing and movable between an upper position and a lower position and having a ring-type seat disposed around the bore thereof near the lower end, an axially hollow anvil slideably disposed within and closely fitting said housing and positioned adjacent one end of said hammer, an annular anvil seat in the upper end of the anvil bore, said hammer being reciprocated between an upper position away from and a lower position contacting said anvil by valve action of valve means on a fluid stream flowing in the axially main hollow portion, said hammer including an annular valve seat thereon, the improved hammer annular seat comprising:

a hammer annular seat supported at the lower interior of the bore of said hammer, said annular seat being concentric with the bore of said hollow hammer; an auxiliary bore of short longitudinal dimension immediately above and adjacent said hammer annular seat, said auxiliary bore (91) being eccentric with respect to the main bore of said hammer.

14. A percussion drilling tool as defined in claim 13 including:

a first bore in the upper end of said anvil which is tangent to the upper end of the arc formed by a vertical plane passing through said valve seat;

a second bore below the lower portion of said annular seat;

a main bore;

said first bore and said main bore each having a center on the center axis of said anvil, said second bore being eccentric to said first bore, said second bore having a diameter not greater than said smallest diameter of said annular seat.

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NILE C. BYERS, JR., Primary Examiner

U.S. Cl. X.R.

175—296
It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 36, after "same" insert --time--.
Column 5, line 1, "cannel" should read --channel--.
Column 5, line 6, "in" should read --is--.
Column 6, line 40, "annual" should read --annular--.
Column 6, line 65, "primary" should read --primary--.
Column 9, line 20, the second "86" should read --87--.
Column 9, line 35, "position" should read --piston--.
Column 10, line 52, "." should be --.--.
Column 10, line 57, "surfaces" should read --surfaces--.
Column 11, line 64, "heat" should read --seat--.
Column 11, line 71, before "guide" insert --valve--.
Column 11, line 72, "sail" should read --said--.
Column 12, line 44, after "the" insert --second--.
Column 13, line 16, after the first "the" omit "the".
Column 13, line 34, "uper" should read --upper--.
Column 13, line 52, after "bore;" insert --a main bore;--.
Column 14, line 23, "groove" should read --grooves--.

Column 14, line 54, after "center" insert --on--.

SIGNED AND SEALED
JUN 30 1970

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Attesting Officer

WILLIAM E. SCHUYLER, J
Commissioner of Patent